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DISTRIBUTIONS AND PHASE-RESOLVED PATTERNS OF PARTIAL DISCHARGES FORMS IN NON-UNIFORM ELECTRIC FIELD IN AIR

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Abstract: Corona discharge is a form of partial discharges (PD) occurring at non-uniform electric field in air. This kind of discharges could be very useful in practical electrotechnology application, however in many cases corona discharges lead to serious technical problems. Corona discharge is a source of electro-magnetic interferences of wide frequency range, and e.g. during electrical power equipment diagnostic measurements at AC testing voltages it produces unneeded quasi-synchronic disturbances.

Paper presents results of corona discharges investigations by means of partial discharge phase-resolved measurement method. Model needle-to-plane electrode systems were used during laboratory experiments as well defined corona discharge sources.

PD forms and phase-resolved PD patterns were observed and analyzed for different setup and testing voltage parameters.

Keywords: partial discharges in air, disturbances, phase-resolved PD patterns

1. INTRODUCTION

Corona discharge is one of the form of partial discharges occurring at high value non-uniform electric field in air. This kind of discharges could be very useful in practice (e.g. in electrofilter systems), however in many cases corona discharges lead to serious technical problems, for example on HV transmission lines. Corona is also a source of E-M interferences of wide frequency range, and during electrical power equipment diagnostic measurements it produces unneeded disturbances (Fig. 1) [1].

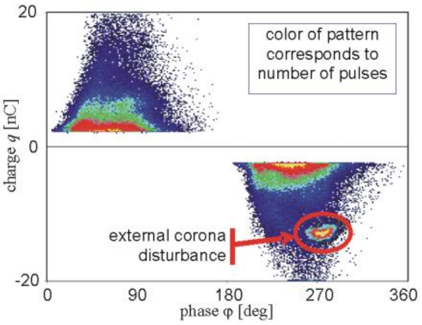

Fig. 1. The PD *φ-q-n* pattern for thermosetting insulation of rotating machine superimposed by corona disturbances

Partial discharges in air exhibit different forms, which depend on such factors as air conditions (i.e., temperature, pressure, and humidity), electrode arrangement, kind of testing voltage (AC/DC) and its polarity. There have been many experimental investigations of the onset PD voltage for different electrode configurations i.e., wires, spheres, needles, and for different conditions, for example different voltage polarity, variable gas pressure and others [2-6].

Partial discharges in non-uniform electric field in air are corona type discharges that are common for elements with small radius of electrode (sharp elements like tip of needle or sharp edges). The needle-to-plane electrode arrangements are often used in investigations of mechanism of discharge in non-uniform electric field in air and usually the needle-tip radius, the gap distance and the magnitude of the voltage are used to describe the insulating system and experiment conditions.

Needle-to-plane setup is a model of discharges on the outer part of electric devices or apparatus referred as corona discharges as well as a model of discharges inside insulating material that are caused by micro tips inside device insulation. The first type of discharges are typical for disturbances in electric field of insulating system which is installed outside the device, the second type of discharges are caused by non-homogenous structure of insulating material.

The majority of published studies refers to DC voltages because of its simpler mechanism than at AC but results of these works can not be applied for interpretation of partial discharges mechanisms in case of alternating voltages.

In the paper, the problem of corona disturbances generated at AC testing voltage and their influence on PD phase-resolved data is presented. Partial discharge forms and corresponding phase-resolved PD patterns for needle-plane setups are observed and analyzed for:

– different arrangements of electrodes,
– positive and negative part of period,
– increasing value of testing voltage.

Described experiment exhibits corona type discharges, which exist in strong electric fields in the vicinity of sharp electrode of small radii.

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2. DISCHARGE PULSE FORMATION IN NON-UNIFORM ELECTRIC FIELD

In the case of corona in air, the space charge plays the essential role in mechanism of partial discharge formation when electric field value reaches appropriate level [2-5]. The ionization zone around corona electrode is represented in Figure 2 by capacitance C_c. In this zone space charge and discharge pulses form [7]. Negative space charges are negative ions formed as result of electrons attachment by oxygen atoms. Negative charges are also formed by small particles of dust, which exist in the air.

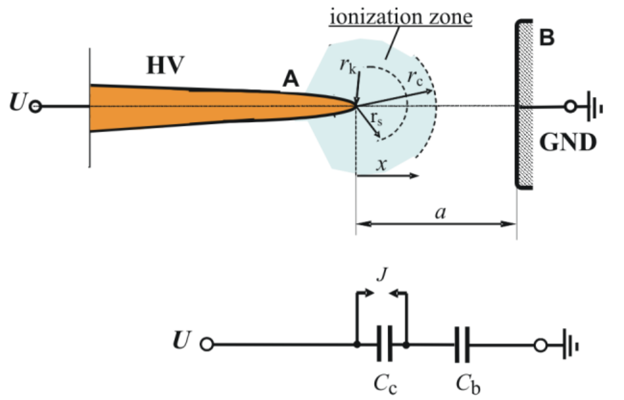

Fig 2. Needle-to-plane electrode arrangement for discharges in non- uniform field, A – needle electrode, B – plane electrode, a – needle to plane distance, r_k – tip radius of needle electrode, r_c – radius of ionization zone [7]

At non-uniform electric field the main form of discharges are avalanches, streamer discharges, and corona discharges. All forms of partial discharges in normal conditions of air (pressure, temperature) and similar to normal ones and measured at onset voltage U_0 to approximately $1.5U_0$ are pulse type and show the stochastic character [4,5,10]. The problem of instability of impulses concerns not only determination of onset voltage but generally different type of mechanism at much higher test voltages than at onset voltage level. Acquisition of PD pulses in an especially arranged model setup shows that PD charges have stochastic character in respect of amplitude and their phase in a voltage period. The investigation of individual features of amplitude-phase sets of discharge pulses is possible by measuring phase distribution of impulses and acquisition of PD phase-resolved patterns – i.e. PD pulses collected in phase-charge-number matrix [6,9].

At the negative polarity of needle, the negative space charge is formed by negative ions generated as the effect of electrons attachment by oxygen atoms. Positive space charge zone is limited only to very small distance from needle electrode, where conditions for impact ionization are present. Then, ions movement towards anode determines discharge current. Velocity v_- of ions in electric field E is described by formula [5]:

$$v_- = u_- E(x) = \frac{dx}{dt} \qquad (1)$$

where: u_- – negative ions mobility

The distance of ions flow is approximately the same as distance between electrodes, thus time of ions existence between electrodes is described by formula:

$$t_- = \int_0^a \frac{dx}{v_-} = \int_0^a \frac{dx}{u_- E(x)} \qquad (2)$$

Electric field E along axis x between electrodes is described by formula [5,6]:

$$E(x) = \frac{2U}{\ln\left(\frac{4a}{r_k}\right)} \cdot \frac{1}{2x + r_k - \frac{x^2}{a}} \qquad (3)$$

Electric field E_r on the surface of needle electrode is a parameter characteristic for defects in form of micro tips in gaseous or solid insulation.

Time of negative ions movement between electrodes, i.e. time of separate, single discharge can be approximated by formula [5]:

$$t_- = \frac{1}{3} a^2 \frac{\ln\left(\frac{4a}{r}\right)}{u_- U} \qquad (4)$$

where: t_- is time interval between discharges, this time affect the intensity of discharges when test voltage $U > U_o$, (U_o – onset voltage).

When onset voltage U_o is applied the first discharge impulse is formed, the first discharge occurs when sinusoidal test voltage reaches the highest level (in positive or negative part of voltage period – it depends on polarity of needle electrode). When high voltage is applied to needle electrode and plane is grounded, the first PD discharge occurs in negative part of voltage period (Fig. 3). When electrode arrangement is opposite, the situation is opposite too i.e. the first pulse arises in positive half-period [7,9].

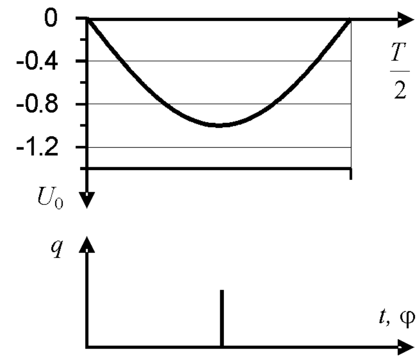

Fig. 3. PD pulse with q charge at inception voltage U_0

Rising the test voltage more than onset voltage $U > U_o$ forms more PD pulses which are situated symmetrically around the first discharge. In theory, amplitudes of all discharges are equal and number of discharges in half-period rises along with test voltage. The mean value of discharges in half-period is described by formula:

$$N = \frac{t_w}{t_-} \quad \text{or} \quad N = \frac{t_w}{\Delta t} \qquad (5)$$

where: t_w – time range in half-period when discharges occurs, Δt – time interval between consecutive discharges.

Time t_w in half-period (when PD discharges occurs) for any value of testing voltage can be calculated as (Fig. 4):

$$t_w = 0{,}5T - 2\frac{\varphi_w}{360}T \qquad (6)$$

Time of discharges presence t_w and phase range Z_φ in a half-period of testing voltage are a function of applied voltage value.

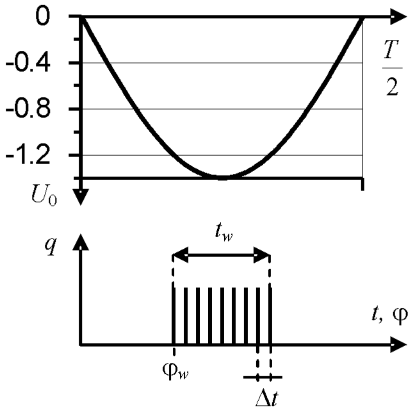

Fig. 4. PD pulses at negative half-period of testing voltage

3. MEASURING METHOD AND SETUP

During experiments the PD phase-resolved measurement method based on using of digital storage oscilloscope DSO (Fig. 5) or partial discharge analyser (PDA) has been applied for data acquisition [1]. Discharge current pulses were detected in classic quasi-integrating wideband circuit according to IEC-60270 standard [11].

For better sensitivity measuring impedance Z_m was connected in series to needle-to-plane electrode system. Resistive high voltage divider R_1-R_2 was used as a source of synchronising signal.

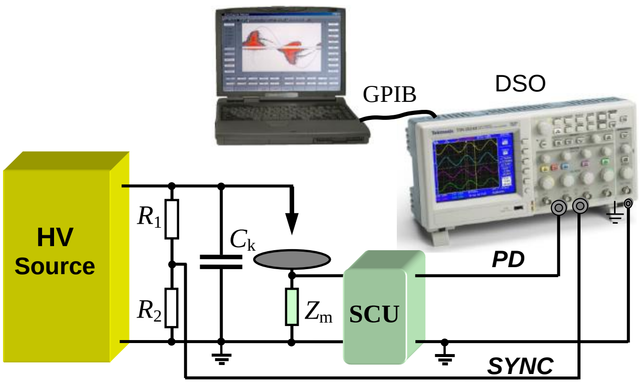

Fig. 5. Experimental setup with DSO: R_1/R_2 – high voltage divider; C_k – coupling capacitor, Z_m – measuring impedance; SCU – signal conditioning unit

For PD pulses sets individual pulses parameters were extracted from registered voltage waveforms (Fig. 6). Small amplitude noises not exceed selected threshold level *LLD* were removed, and then phase- and amplitude- distributions have been composed.

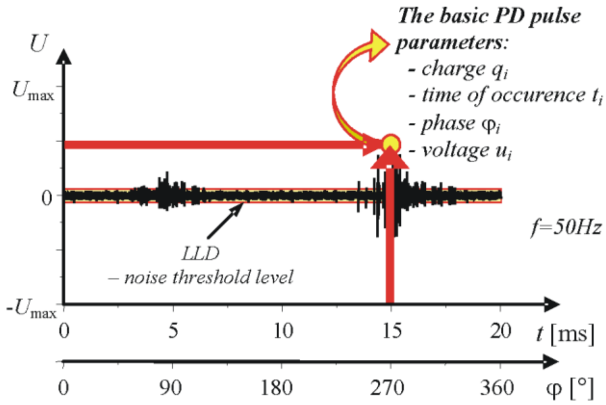

Fig. 6. The pulse parameters extraction for phase-resolved PD data analysis

4. RESULTS OF CORONA DISCHARGES MEASUREMENTS

The laboratory measurements in the model electrode arrangement with variable distance in the needle-to-plane configuration and with a needle electrodes tip radii of 300 μm has been carried-out. Figure 7 presents results in the form of *φ-q-n* patterns registered during 60 second acquisition time by PDA system (*ICMsystem* - Power Diagnostix) and evaluated in Matlab® program for two opposite needle-to-plane configurations with HV at needle or HV at plane applied (electrode distance = 4 cm).

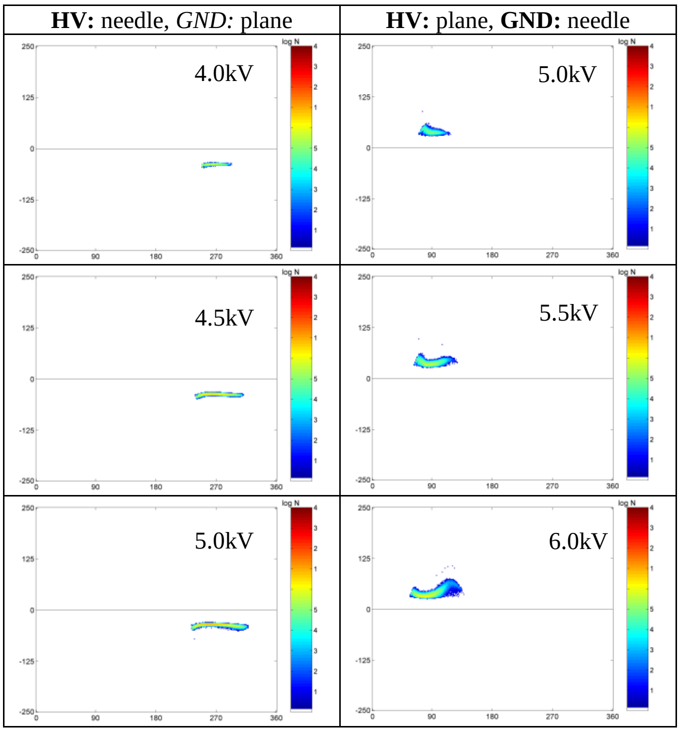

Fig. 7. Results of corona pulses acquisition in *φ-q-n* patterns for two opposite setups: needle-to-plane (left) and plane-to-needle (right) setup (acquisition time = 60 s)

Results of measurements for doubled needle-to-plane electrode systems with opposite position of two needles are presented in the Figure 8 (needles radii "+": 300 μm and "-": 450 μm).

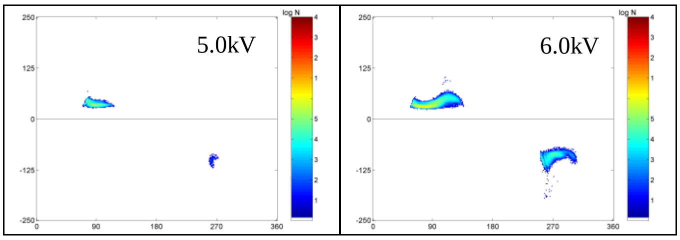

Fig. 8. Results of PD pulses acquisition in *φ-q-n* patterns for two coupled needle-to-plane electrode systems with opposite position of the needles (acquisition time = 60 s)

Figure 9 presents examples of phase-charge Dq(φ) and charge-number Dn(q) distributions evaluated for single period data, collected for the same setup as for Figure 8. Registered pulses show stochastic character of corona discharge phenomena.

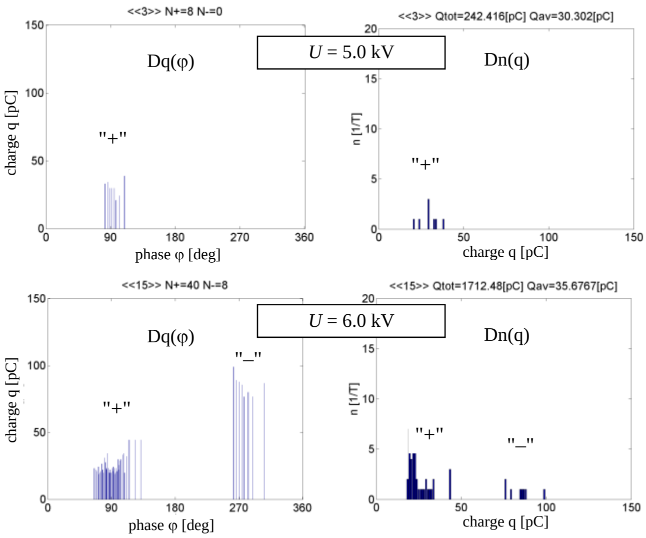

Fig. 9. Examples of phase-charge Dq(φ) and charge-number Dn(q) distributions for single period at different voltages

5. CONCLUSIONS

Pulse type discharges are typical form of discharges initiated by ionization processes and effects of space charge.

Pulse type discharges occurring in period of AC voltage are directly related to mechanism of discharges that depends on electrodes polarity.

Phase ranges around 90° and 270° of voltage period are typical for PD in non-uniform electric field in air.

The form of phase-number distributions and phase-resolved PD patterns in air depend on experiment conditions e.g. needle tip radius and distance between electrodes influence corona inception voltage and average apparent charge of PD pulses.

Phase-resolved patterns of corona in air are also typical for electrical field disturbances during electrical power equipment testing. It make possible to identify the type of disturbances in these conditions.

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ROZKŁADY I OBRAZY FAZOWE FORM WYŁADOWAŃ NIEZUPEŁNYCH W NIEJEDNORODNYM POLU ELEKTRYCZNYM W POWIETRZU

Słowa kluczowe: wyładowania niezupełne w powietrzu, zakłócenia, obrazy fazowo-rozdzielcze wnz

Wyładowania niezupełne w powietrzu w polu niejednorodnym są jedną z form wyładowań elektrycznych. Wyładowania te znajdują zastosowanie w pewnych aplikacjach technologicznych, jednak w wielu przypadkach powodują poważne problemy techniczne. Są źródłem zaburzeń elektromagnetycznych i podczas badań diagnostycznych urządzeń elektroenergetycznych napięciem przemiennym powodują powstawanie niepożądanych zakłóceń quasi-synchronicznych. Artykuł przedstawia wyniki badań wnz w polu niejednorodnym metodą pomiarów fazowo-rozdzielczych. Zastosowano układy modelowe elektrod typu ostrze-płaszczyzna. Rejestrowano obrazy fazowo-rozdzielcze dla różnych konfiguracji elektrod i wartości napięć probierczych.